2006-1931: AN INTER-DISCIPLINARY PROJECT COMBINING CNC MACHINING AND DESIGN OF EXPERIMENTS

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Introduction

A key requirement for graduating engineers is the ability to work successfully on inter-disciplinary teams. Each of the team members brings different knowledge and skills to the team. This project, a joint project between courses in Computer Numerical Control (CNC) machining and Design of Experiments (DoE), provided the opportunity for industrial, manufacturing, and mechanical engineering students to investigate some of the key factors (parameters or variables) related to machining process.

Machining is a multi-billion dollar industry. It is critical for machining operations to manage both quality of part and cutting tools life. Quality of part includes conform dimensional specification and surface finish requirements of the part. Cutting tool life governs not only the cost of individual cutting tools, but the amount of time and money spent to change tools, when a tool is worn out. The cost of a tool change may easily exceed the cost of the cutting tool itself. It is clearly in the interest of the manufacturer to optimize tool life and part quality. Designed experiments are a useful statistical tool for this type of investigation. In this project, the focus was on using DoE to select the best tool geometry and cutting conditions.

An Integrated Project using Designed Experiments

The first step in the methodology was to define the problem for the students. The problem was to design and perform an experiment using a 2^4 factorial design, which would address the problem of optimizing cutting conditions using factors of feed, speed, depth of cut, and cutting tool geometry. The outputs measured were surface finish of the part and wear of the tool. In this paper, the authors used one team project to show how the experimental design was generated, data collected and analyzed, and practical conclusions obtained. Only surface finish data were shown in this paper.

Based on the discussions and feasibility of the lab schedule, the factors and levels chosen for the experiment are shown in Table 1.

Table 1. Factors and Levels of the Experiment

	Levels	
Factors	***Low (-1)***	***High (+1)***
Insert Geometry (**A**)	Normal	Wiper
Cutting Speed (**B**)	800 SFM	900 SFM
Feed Rate (**C**)	0.006 in/rev	0.008 in/rev
Depth of Cut (**D**)	0.050 in	0.075 in

The tools used by the students were Kennametal CNMG 12 04 08 FW and FN inserts. The geometries represent different chip breakers, where FW is a wiper insert designed to produce a better surface finish. Inserts were finishing inserts of KC9110 grade. Separate tool edges were used for each cutting speed. The machining operation was performed on 2 inch (5.08 cm) bars of 1045 steel. Prior to the performing the experiment, bars were cut to length, faced, and one end prepped for the chuck. This resulted in bars of standard 6 inch (15.24 cm) length with a 4 inch (10.16 cm) length available for cutting. Machining was performed on a Haas HL-2 CNC lathe without cutting fluid.

Students were assigned by faculty to one of four teams. To the extent possible, each team was composed of members from each of the major fields represented in the class. The teams were also divided as evenly as possible between the two classes. There were three students taking both courses at the same time.

Scheduling of testing and analysis was the responsibility of each group. Faculty provided resources as needed, however they were not directly involved in project management.

DoE class team members used Minitab software to generate randomized experimental runs sheets. CNC class team members used the sheet to run the experiment. Two surface finish measurements were taken and the average value was used for each machined part. Data from the surface finish experiment are shown in Table 2.

Table 2. Data Collection with Surface Finish Measurement

Run Order	**Part Number**	**Insert A**	**Speed B**	**Feed C**	**Depth of Cut D**	**RA 1**	**RA 2**	**RA Avg**
1	3	Normal	900	0.006	0.05	47.5	46.3	46.9
2	6	Wiper	800	0.008	0.05	21.6	36.3	28.95
3	12	Wiper	900	0.006	0.075	28.7	40.2	34.45
4	4	Wiper	900	0.006	0.05	40	45.4	42.7
5	11	Normal	900	0.006	0.075	55.4	55.7	55.55
6	1	Normal	800	0.006	0.05	42.8	41.9	42.35
7	10	Wiper	800	0.006	0.075	47.6	51.7	49.65
8	16	Wiper	900	0.008	0.075	32.4	29.6	31
9	9	Normal	800	0.006	0.075	60.3	59.8	60.05
10	13	Normal	800	0.008	0.075	87.7	75	81.35
11	15	Normal	900	0.008	0.075	88.4	87.5	87.95
12	14	Wiper	800	0.008	0.075	44.2	47.5	45.85
13	8	Wiper	900	0.008	0.05	20.8	26.2	23.5
14	5	Normal	800	0.008	0.05	93.3	92.4	92.85
15	7	Normal	900	0.008	0.05	84.3	83.5	83.9
16	2	Wiper	800	0.006	0.05	22.2	32.2	27.2

Using Minitab's normality probability plot for the effects shown in figure 1, the team identified that factor A (insert geometry), factor C (feed rate) and the interaction AC are statistically significant. The main effects plot for factor A and factor C are shown in figure 2 and the interaction plot is shown in figure 3. The plots provide the graphical view of the significant factors and their interaction.

Figure 1. Normal Probability Plot of the effects

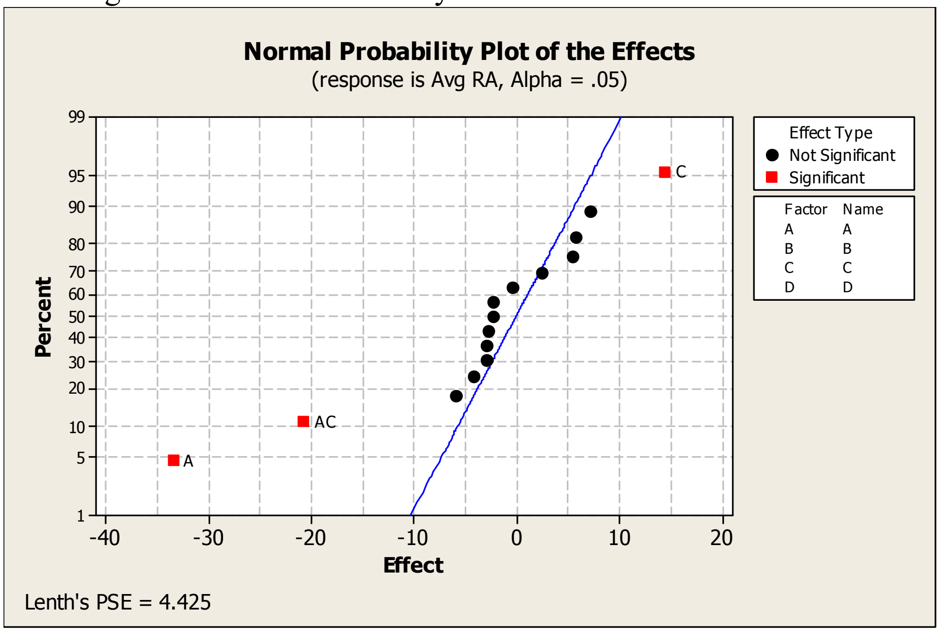


Figure 2. Main Effects Plot

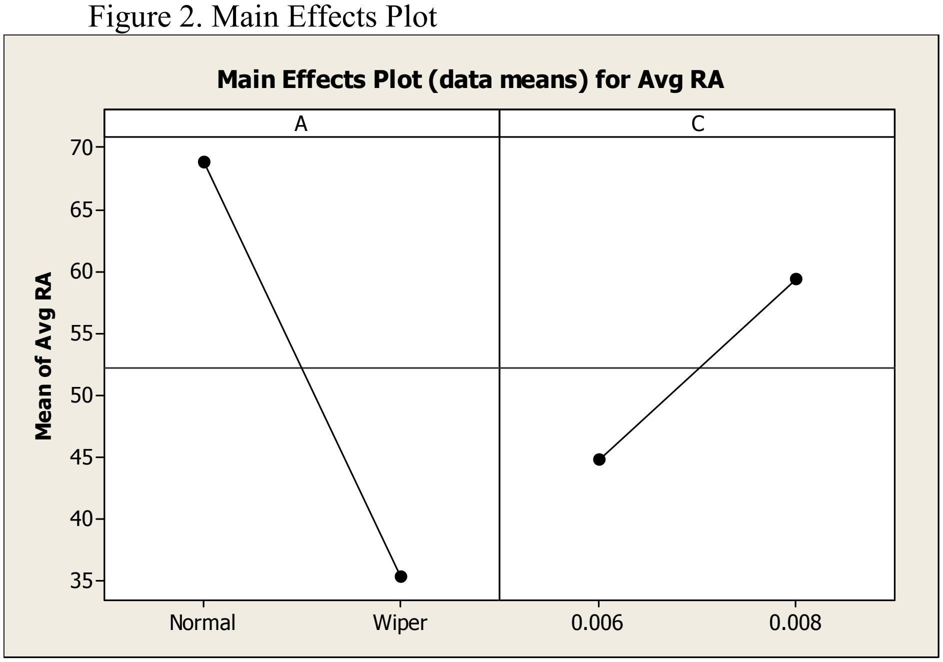
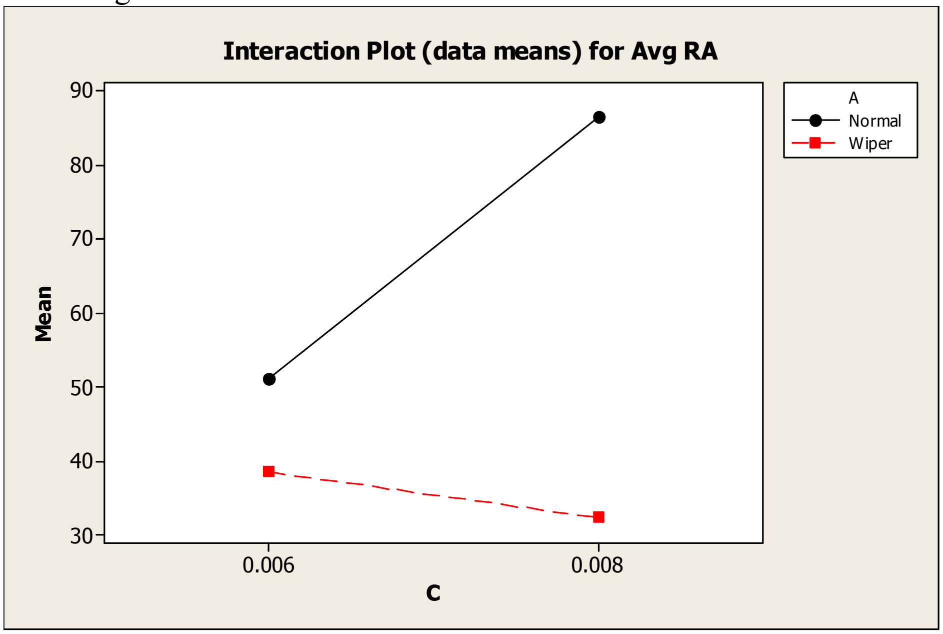


Figure 3. Interaction Plot



Practical conclusions from the graphical analysis are as follows:

1. Insert geometry, feed rate, and their interaction had significant impact on the part surface finish.
2. The interaction plot shows that the best surface finish is produced by the combination of the wiper insert and high feed rate.

An estimated regression model can be obtained from the Minitab for the surface finish evaluation. The Minitab regression output is shown in table 3. The estimated surface finish prediction model is given by equation (1).

Table 3. Estimated Coefficients for Regression Model

Estimated Regression Coefficients for Avg RA

Term	Coef	SE Coef	T	P
Constant	52.138	2.079	25.080	0.000
A Coded	-16.725	2.079	-8.045	0.000
C	7.281	2.079	3.502	0.004
A Coded*C	-10.369	2.079	-4.988	0.000

S = 8.316   R-Sq = 89.5%   R-Sq(adj) = 86.8%

$$Y = 52.138 - 16.725A + 7.281C - 10.369A*C \quad (1)$$

Discussion

There are two sets of results for this project. The first is pedagogical. The dynamics of the groups were significantly different. This was in part due to the varying strength of the team leaders. In the case of the least assertive team leader, one of the team members essentially took over leadership. Additional concerns had to do with care in following the methodology and use of the tools. Kettering students are under considerable time pressure (Kettering University's term is only 12 weeks long) and procrastination can be a very large problem. Two of the groups did most of the testing over a two day period in the ninth week of the term. This caused considerable schedule compression, especially when one group broke a tool. There was also damage caused to a tool bar, which required a rapid faculty response to order a new bar and delayed testing for 4 days. In all cases the testing was completed and so was the analysis.

The reports and presentations prepared by the groups showed fundamental competence in the subject areas. Even among seniors, however, there was still a significant barrier between using the data analysis methods and providing a physical interpretation of the results. Students did not independently look for reference materials with which to compare their experimental results. While the course materials were mentioned, there was no clear discussion of why some experimental results may not have been consistent with the expected results from lecture.

There are seemingly two reasons for the issue of data interpretation to arise. The first has to do with division of labor within the group. While the groups were multi-disciplinary, some of the groups divided themselves into subgroups specializing in either data collection or data analysis. When this happened it became difficult for the two subgroups to effectively communicate. This contributed to preventing physical interpretation of the results, since the two subgroups did not integrate expertise well.

The other reason for difficulty in data interpretation was what appeared to be a mentality of compartmentalization. Students are very accustomed to working with course specific information and had some difficulty crossing between the two courses. This included the students enrolled in both courses.

The second set of results is technical. As can be seen from one team's project outcome, using experimental design, performing the experiment, collecting and analyzing the data and deriving practical conclusions, the students did learn the use of DoE and Minitab for a close to real world problem solving experience. They used the DoE tool to identify factors and their interaction that will impact part surface finish, and are able to establish a basic model between the part surface finish and the significant factors involved.

Conclusions

This group of Kettering University seniors was able to successfully work as a multi-disciplinary team in order to complete a very realistic project – in this case a tool study. There are other issues, however, which relate directly to the performance of the group. These are:

- Project Management skills, particularly scheduling
- Integrating information across courses
- Interpretation of data, specifically relating the results to physical phenomena.

These issues suggest areas that need greater emphasis in the curricula of Kettering University.

Results of the machining study were as expected. The wiper insert design is meant to produce better finishes at higher speeds and feeds than convention geometries. The statistical analyses of the results clearly show this.

Bibliography

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Acknowledgement

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